A SHORT- TERM STUDY OF BEACH SAND MIGRATION ADJACENT TO MONTEREY CANYON

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ABSTRACT

The movement of sand in the swash-zone south of the head of Monterey Canyon was studied during February and March, 1966. A stationary sampler was designed and used in conjunction with dyed fluorescent sands to trace the rate and direction of natural sand movement. A sequential multiple linear regression program was used to statistically analyze the effects of this canyon and several other environmental parameters on the movement of beach sand. In all observations made, the sand was found to move toward the canyon head. The canyon also appears to be a major factor affecting the rate of beach sand drift.

TABLE OF CONTENTS

Section		Page
1.	INTRODUCTION	11
	The Problem	11
	Background	11
	Organization	14
2.	STUDY TECHNIQUES	17
	Discussion	17
	Sand Movements	17
	Interactions	19
3.	THE STUDY	21
	Location	21
	Rate and Direction of Drift	21
	Parameters Used	23
	Interaction Analysis	24
4.	PROCEDURES	25
	Data Collection	25
	Data Analysis	28
	Data Processing	30
5.	RESULTS	41
	Direction of Sand Movement	41
	Rate of Sand Movement	41
6.	CONCLUSIONS	47
7.	FUTURE STUDY	53

8. ACKNOWLEDGMENTS 55

BIBLIOGRAPHY 57

APPENDIX I Description and Measurement of the Studied Variables 59

APPENDIX II Sample Data Analysis Sheets 63

LIST OF TABLES

		Page
1.	Observational Data	31
2.	Fictitious Example for Three X's	34
3.	Contributions by Additional Variables Among the Eight Strongest Independent Variables Taken Jointly	37
3A.	Contributions by Additional Variables Among the Six Strongest Independent Variables Taken Jointly	38
4.	A Typical BMD Type Output for a Stepwise Multiple Linear Regression	39
5.	The Strongest Percent Reduction in Sand Drift Sum of Squares Attributable to Each of Several Combinations of Eleven Independent Variables	42
6.	Range and Mean Rate of Sand Drift at Each Station	46
7.	Sand Drift Rates for Each Observation for Phi Ranges -1 through 4	51

LIST OF ILLUSTRATIONS

Figure		Page
1.	Typical Wave Refraction, Monterey Bay	13
2.	Station Grid Locations	15
3.	Sampling Techniques	22
4.	Sampling Device	27

TABLE OF SYMBOLS

SYMBOL	DESCRIPTION	UNITS
H_b	Breaker Height	Feet
a	Angle of Approach	Degrees Right or Left
M	Mean Slope of Swash-Zone	Degrees from Horiz.
V_{ON}	Onshore Wind Component	Knots
V_{LONG}	Longshore Wind Component	Knots
D_C	Distance from Canyon	Feet
C_L	Longshore Current	Feet per Second
D_{50}	Mean Grain Size	Millimeters
H_T	Height of the Tide	Feet above MLLW
V_S	Swash Velocity	Feet per Second
T	Wave Period	Seconds
Y	Rate of Sand Drift	Feet per Minute

1. INTRODUCTION

The Problem

Monterey Bay provides a unique area for the investigation of submarine canyon effects on beach-sand migration. The object of this study is to determine, through a statistical approach, the effects of the Monterey Canyon, as well as that of several other measured parameters, on the rate and direction of swash-zone sand movement.

In recent years, a considerable degree of progress has been achieved in the field of beach-sand dynamics and transport processes. Of particular interest is the interaction occurring between the beach and environmental factors. Also of interest is the relative contribution that the individual parameters make to the net movement of beach sand. Due to the large number of agents interacting in this situation, the problem is complex and difficult to resolve without employing a statistical approach. It is proposed then, that by measuring the environmental parameters and applying a statistical analysis, a meaningful set of relationships can be obtained.

Background

Chamberlain [1] investigated the littoral sand budget for a series of California beaches associated with submarine canyons. In each of these regions there is a littoral cell containing stable beaches where a balance exists between sediment input and loss.

Typically, each cell is bounded on one side by rocky headlands where the influx of sand is restricted. Within the cell, the sand is supplied to the littoral zone by coastal streams and rivers, and is transported along the coast. The presence of the canyon head acts as a terminal point for the cell and intercepts the littoral sand which is then transported down the canyon. Previously, Sheppard [8] noted this effect in a series of detailed measurements made in La Jolla Canyon. He found that the head filled at a rate approximately equal to the average net transport rate of sand for the entire region, and that it subsequently slumped into the canyon through the mechanism of turbidity currents.

In general, the net result of a submarine canyon with its head extending into shallow water is a central region of low wave energy surrounded by regions of higher wave energy [10]. In Monterey Bay, refraction patterns clearly indicate a region of energy divergence located directly over the canyon with adjacent zones of energy convergence (Fig. 1). Conservation of energy and continuity considerations provide for a net movement of water into the divergent area, resulting in average littoral currents directed toward the canyon from both sides. The largest instantaneous rates should occur nearest the canyon head [9]. This line of reasoning can also be extended to include the littoral drift problem, where again, the largest rates would be expected in the vicinity of the canyon head.

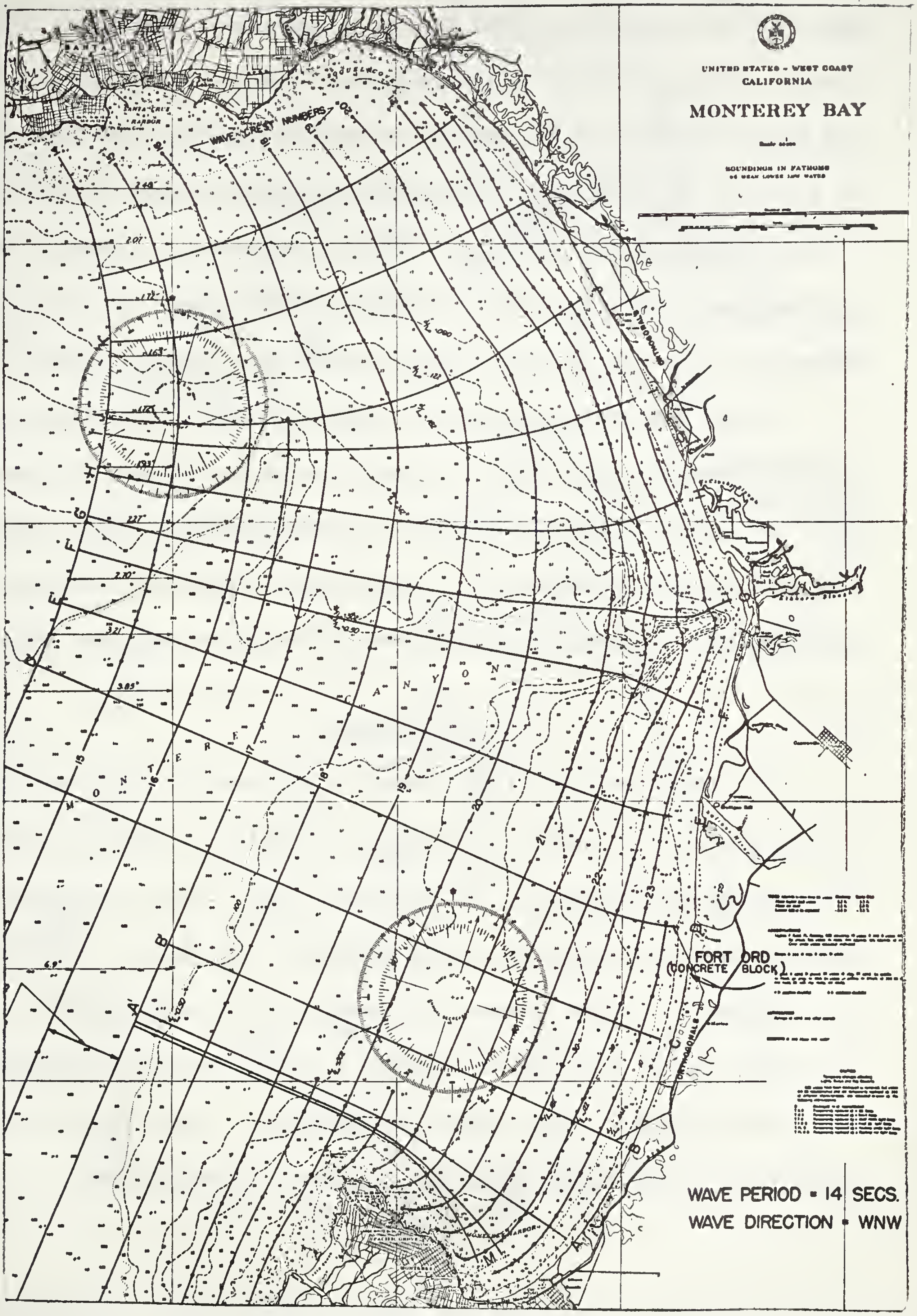

FIGURE 1 - TYPICAL WAVE REFRACTION, MONTEREY BAY

Some indication of these conditions occurring in Monterey Bay has been demonstrated in two separately conducted observations. A study made by Hohenstein, Jaeger, and Jones [5] on Del Monte Beach at the southern end of the bay provided evidence of little or no sand drift occurring on the beaches in that region. A trial investigation conducted by the authors in January 1966, one quarter mile south of the canyon head (point B in Fig. 2), indicated a strong rate of drift toward the canyon head.

These previous remarks all suggest that the presence of the Monterey Canyon might indeed have some effect on beach-sand movement. Since no known studies relating both canyon and environmental effects to beach sand migration have been conducted, a detailed investigation of this problem was desirable.

Organization

The first part of this thesis is concerned with the approach to the problem, including techniques available, methods employed, and related assumptions. In the next part, the procedures involved in data collection, data analysis, and data processing are discussed. Part three is a presentation and analysis of the processed data, while part four is a discussion and interpretation of these results, with related conclusions. The final section deals with recommendations for future related studies.

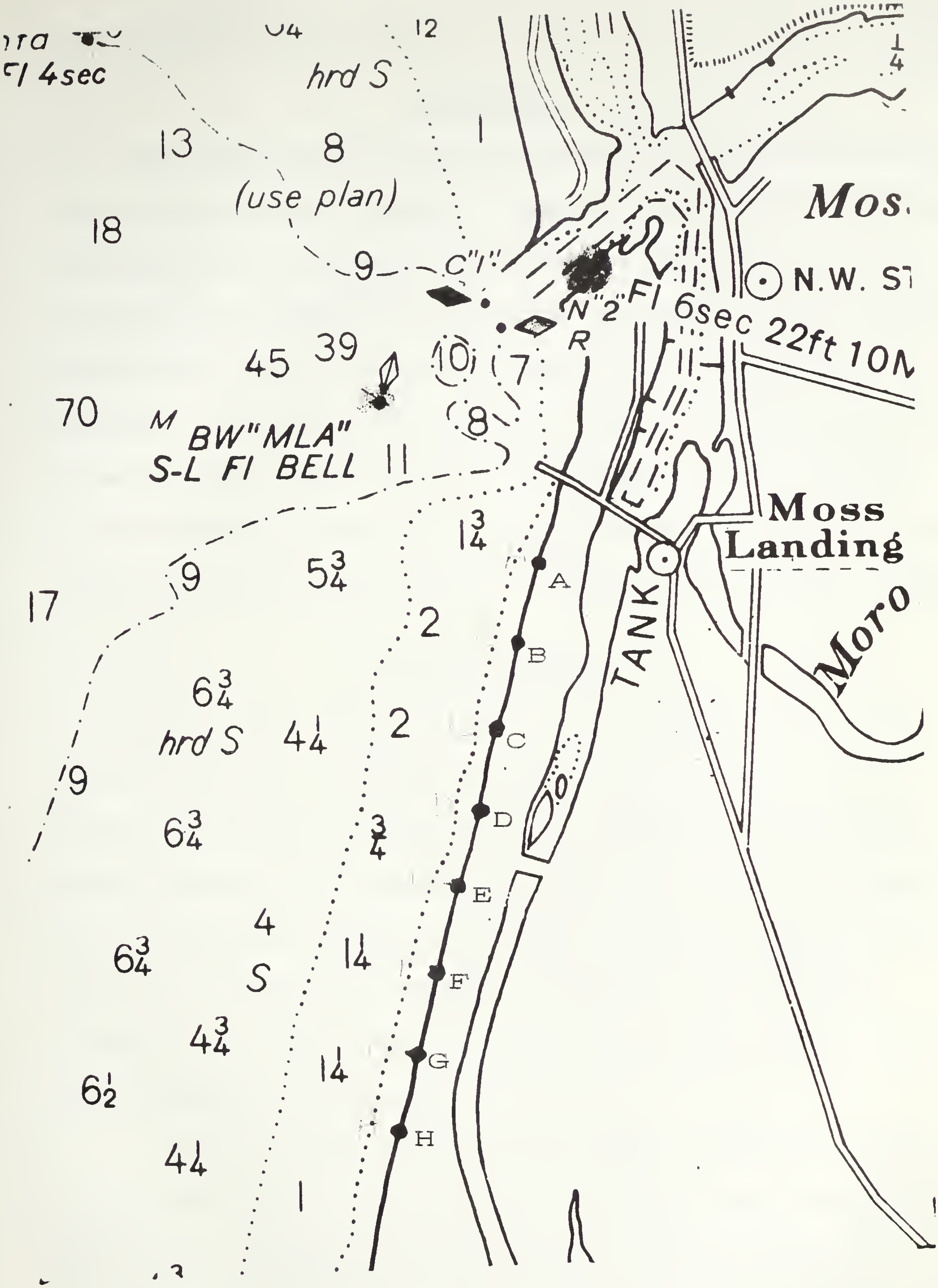

FIGURE 2 - STATION GRID LOCATIONS

2. STUDY TECHNIQUES

Discussion

The basic problem of sand movement is a three-dimensional study in time, having offshore, longshore, and vertical components. A simple problem involving a one-dimensional rate can be treated by ignoring the offshore and vertical components. The resulting problem can then be divided into two easily investigated sub-problems. The first is a determination of the direction of sand movement with respect to the canyon head, and the second is a determination of the rate of sand movement as related to the canyon effects in conjunction with other environmental parameters.

Sand Movement

In the past, determination of sand movement has been a difficult problem. Various techniques have included the use of physical characteristics such as color, shape, size distribution, mineral content, and magnetic properties as identifiable features to trace sand movement. More recent methods primarily employ the use of radioactive particles for tracing silts and clays, painted or dyed tracers for pebbles and cobbles, and dyed fluorescent grains for sands [3].

A representative tracer particle used in a sand movement study must react to fluid forces in a manner closely resembling that of the naturally occurring grains, while maintaining its physical identity. This requires the tracer to have a size, distribution, density, shape, surface chemistry, and strength

similar to the natural beach material. In theory then, if most of the above criteria are satisfied, a tracer may be used to determine a representative value for both the direction and rate of movement of the naturally occurring sands. Ideally, the tracers should be prepared from sands in the beach area where the study is to be conducted. It may be necessary, however, to prepare artificial tracers or natural tracers obtained from a different locale. Care must be exercised to match the tracer characteristics to those of the studied area [11] .

Sampling and analysis techniques may vary depending on the results desired. A space integration sampling method, where tracer counts are made over a multi-sample grid system, provides information on the direction and distribution of sand movements. Subsequent sampling without replacement of the tracer can be used to determine a time rate of particle distribution. This method is slow and requires analysis of a large number of sand samples. A faster, less tedious procedure is the time integration method, where a few samples are obtained in a line normal to the littoral drift. Periodic sampling at a given distance from the injection point will establish a rate by providing the time at which a significant number of marked grains reaches the sampling point [12] . Laboratory determinations in conjunction with the above sampling methods can provide both qualitative and semi-quantitative results. The direction and rate values obtained are qualitative in that only relative concentrations of the tracers

are important. Quantitative observations involve major assumptions as to the vertical and seaward distribution of the tracer particles.

Interactions

Reliance upon information supplied by direct observations, in which inferences are made regarding the physical relationships of the agents acting, suggests that the study of beach processes should be primarily statistical. This approach provides a rational basis for the study of beach phenomena because it includes the following features. A specific set of variables is measured, and a plan for sampling at random times and places is designated. An analysis of the data locates the sources of variability and the results are used to predict relationships among these agents [6].

There are several statistical models which can be used. Multiple regression analysis, correlation analysis, factor analysis, and discriminant function analysis are all useful in particular situations [7].

3. THE STUDY

Location

The field phase of this study was conducted on a stretch of beach extending southward from the Moss Landing Pier (Fig. 2). Physical sampling complexities restricted the study to considering only those movements in the surface layer of the swash-zone. Time and transportation deficiencies also limited the study to one side of the canyon and a longshore extent of approximately one mile. The head of the canyon was chosen to be the point where the offshore contours sharply closed the beach near the end of the pier (Fig. 2). Inspection of the contours one mile south of the pier indicated that this distance would be sufficient to recognize a difference in canyon effects, if any existed.

Rate and Direction of Drift

Since the study area was a sand beach, the drift rate and direction determinations were obtained using dyed fluorescent tracers in a time integration sampling technique. Preliminary studies considered only sand movements toward the canyon and sampling was conducted on the canyon side of the injection point (Fig. 3a). Subsequent evidence revealed that single-side sampling did not provide discrimination between positive drift and dispersion. Therefore, a single sampler with two opposing injection points, having differently colored tracers, was used (Fig. 3b). Hence,

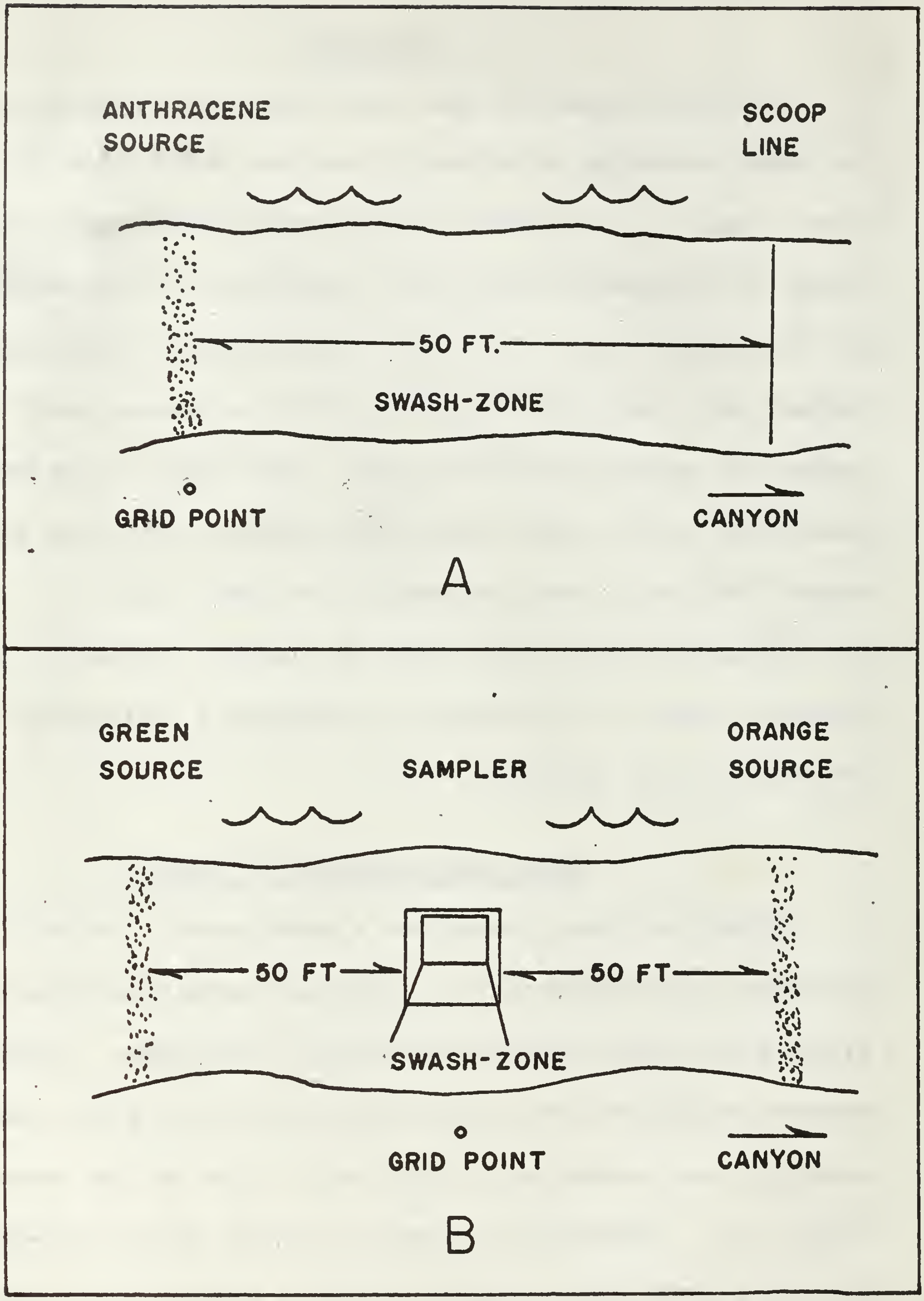

FIGURE 3
SAMPLING TECHNIQUES

direction of drift and dispersion could be positively identified by a single observation.

Parameters Used

To obtain genuine significance from this study, the canyon effects must be evaluated in conjunction with other environmental factors affecting sand drift. In all, eleven independent variables were included in this study.

Distance from the canyon head was chosen as the parameter to represent canyon effects. With increasing distance from the canyon, decreasing refraction causes a more equal distribution of wave energy on the beach, thereby reducing the divergent effects of the canyon and the expected rate of drift. Breaker height, wave period, and angle of approach were chosen to represent the intial energy present and its distribution to the surf zone. Height of the tide regulates the amount of the initial energy which transits the surf zone. In this respect, low tide causes a large amount of energy to be expended on bottom features prior to reaching the swash-zone. [10]. Mean slope in conjunction with swash-length and period was used as a measure of the amount of energy being released to the beach. The latter two were combined as a single parameter, swash-velocity, to provide an indication of the frequency of wave action on the swash-zone. The mean diameter of the grains that moved was used as an indication of the energy being transported along the beach

since large grains would require more energy than smaller grains to be transported a given distance.

The wind was considered because of its ability to locally alter the energy. Two factors are important: the longshore wind component can contribute to the lateral distribution of energy; and the onshore/offshore component can alter existing wave forms [4]. Longshore current with its ability to move sand, has been classically associated with the energy distribution of the aforementioned parameters and was therefore included.

Interaction Analysis

Sequential multiple linear regression was the statistical model chosen to analyze the observed interactions [7]. For this approach to be effective, a high degree of variability of the observed parameters must exist. Ideally, the variable should be measured over the maximum range of values which can be expected during the study period. To adequately investigate the area and still provide sufficient variability in the statistical approach, a minimum of eight to ten grid points, with sufficient grid point spacing, is required. To maximize this effect an eight-point grid spaced at 800-foot intervals was established. To provide confidence in the statistical results, a minimum of three observations per variable considered was required [4].

4. PROCEDURES

Data Collection

The initial step in the data collection phase of the study was the establishment of a sampling station grid. This was accomplished by using a transit and stadia rod. Stations were laid out at 800 foot intervals using the Moss Landing Pier as a base point (Fig. 2).

In order to provide an accurate indication of the grain sizes actually moving along the beach, the tracer sands used had a wide grain size distribution. Orange and green fluorescent tracer sands ranging in size from 0.065 to 1.0 millimeter diameter were utilized for this study. The dyed sands were an artificial mixture of local coastal dune and sea floor sand procured by Hohenstein, et al, for a 1965 beach-sand study [5]. The mixture was coated by the Great American Color Company of Los Angeles, California.

During the period of 2 February through 22 March 1966, the eight sampling stations (Fig. 2) were each visited six times on a random basis. Collections were made under as widely varying environmental conditions as possible.

The first seven observations used fluorescent blue anthracene tracers seeded in the swash-zone at the grid stations. At a position 50 feet toward the canyon from the grid station, a metal can cut to scoop only the upper half-inch of the beach was used to collect a sample in a line through the swash-zone.

A different method of using two colors of dyed sand and seeding on both sides of a stationary sampler (Fig. 4) was utilized throughout the remaining 41 observation periods.

After a station was selected, the sampler was established in the mid swash-zone. It was secured in position with four two-foot iron spikes. This was necessary due to the occasional violent action occurring in the swash-zone.

Prior to tracer seeding, a five-minute sample was obtained to determine a background count of dyed sand that may have been present from previous observations. The next step was to seed approximately five pounds of green tracer 50 feet from the sampler in a direction away from the canyon while simultaneously seeding an equal amount of orange tracer the same distance towards the canyon. Seeding was accomplished by injecting the marked sand in a line normal to the beach immediately behind an outgoing swash (Fig. 3).

To preserve sampling continuity, two collection boxes were used alternately and samples taken at seeding time plus 5, plus 10, plus 15, plus 20, plus 25, plus 30, plus 40, plus 50, and plus 60 minutes. Samples were transferred from the collection boxes to polyethylene bags and appropriately tagged for later analysis.

During the course of each sampling period, the environmental parameters, as described in Appendix I, were measured and recorded.

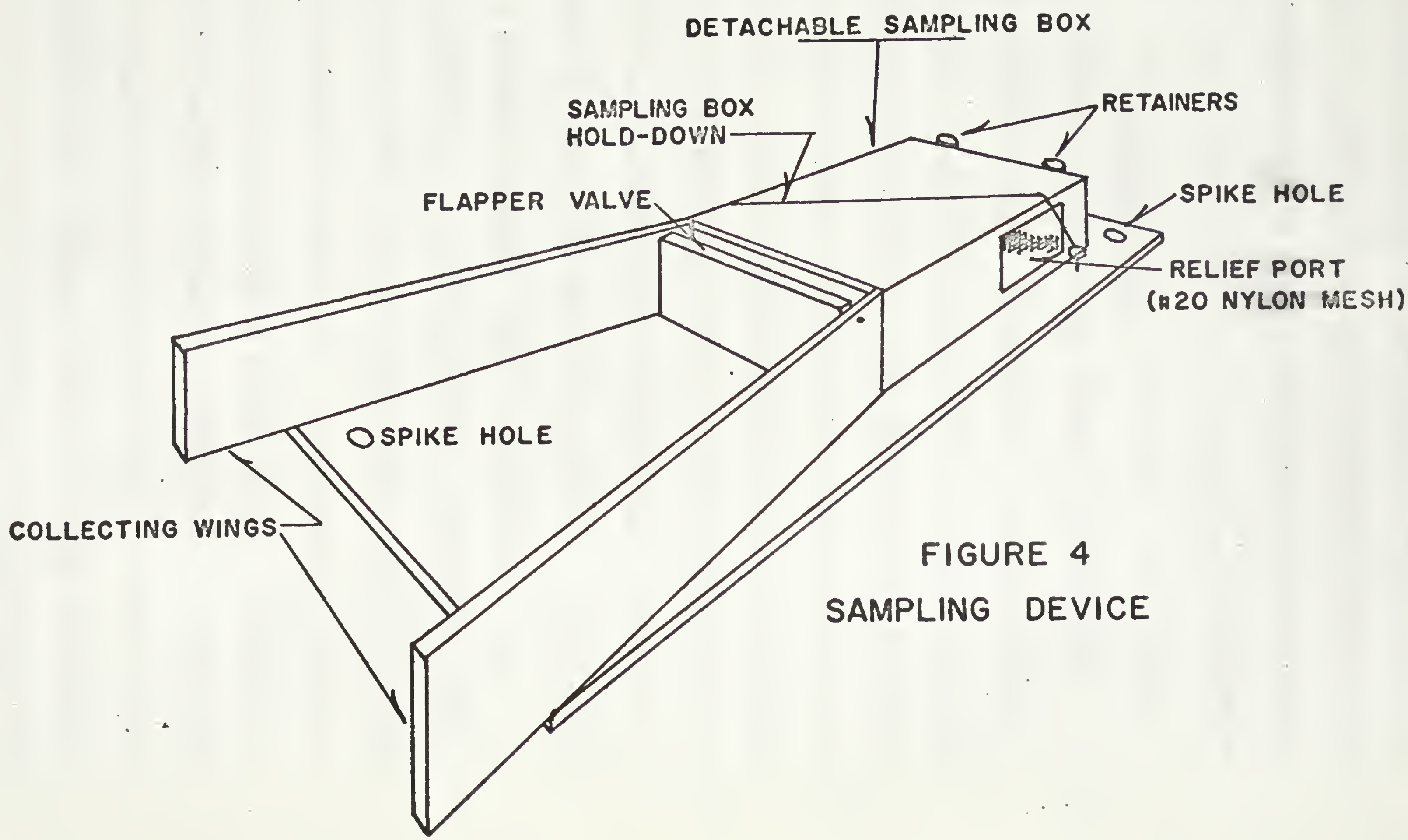

FIGURE 4
SAMPLING DEVICE

Midway through the data collection phase, a Jeep was obtained. Use of this vehicle vastly simplified and accelerated the sampling procedure and made possible a greater number of observations in the limited time frame allocated for data collection.

Data Analysis

After field collections, the 360 sand samples were brought to the laboratory for analysis. Each sample was force-dried in an oven at 250° F. It should be noted that very high temperatures (400-500° F) have a detrimental effect on the fluorescent properties of the marked sand, hence the lower drying temperatures and correspondingly longer drying times were used. Following the drying process the individual samples for each observation were reduced to a given volume to provide a common reference. The samples were then shaken through a nest of six Tyler sieves having mesh openings ranging from 0.061 to 1.981 millimeters. Each grain size was inspected individually under an ultra-violet light and the number of tracer grains counted (Appendix II). In order to accelerate and simplify the counting of tracer grains a multiple-riffle type sample splitter was used. The number of marked grains in a sample was assumed to be: $n=2^{s-1}$ where s is the number of splits required to yield a fraction with no marked grains. This assumption was checked and confirmed by Wright [11].

When the tracer grains had been counted for all samples

in a given observation, a cumulative grain count curve was plotted and a rate of sand drift determined (Appendix II).

As rate of sand drift was the dependent variable in the statistical analysis of the problem, a great deal of study and experimentation was required for the establishment of the criteria to be used in determining this rate. To eliminate erroneous or misleading drift rates caused by anamolous swashes, a significant percentage of the total number of captured grains was chosen. In addition, the region of maximum slope on the cumulative curve indicated that the greatest volume of movement was occurring at that time. The criteria developed was 25% of the total number of captured grains and that this percentage lie on the maximum slope. This established the drift time which allowed for subsequent calculation of the drift rate used in the analysis. In addition, the rates of drift for five phi[1] ranges (-1 to 4) were determined (Appendix II).

The final steps in this phase were to determine mean grain size and reduce the data to a form compatible with the data processing phase (Appendices I, II).

Of the 48 original observations the seven employing anthracene tracers were discarded. Failure of the sampling device resulted in lack of continuity in two more observations and these were also discarded. Three additional observations were not used in the analysis because their total grain count

[1]Phi = $-\log_2(d)$, where d = grain size diameter in millimeters

was less than 10% of the mean grain count of all observations (Table I).

Data Processing

After the data were compiled, they were processed on a CDC 1604 computer. In order to provide all positive inputs to the computer the observed data was corrected to the arbitrary reference levels indicated in Table I. "Whirlpool", a computer program for "sorting out" independent variables by sequential multiple linear regression, was utilized for this procedure [7].

The general linear model may be expressed by:

$$Y = B_0 + B_1 X_1 + \ldots\ldots\ldots + B_k X_k + e,$$

where Y is the dependent variable, $X_1 \ldots\ldots, X_k$ are the parameters measured (independent variables), B_0 is a fixed constant, $B_1, \ldots\ldots\ldots, B_k$ are linear coefficients, and e is a variable error term which includes data "noise" or parameters that were not considered. The general mathematical approach will not be described here, since it is well presented by Krumbein, Benson, and Hempkins [7]. A discussion of the sum of squares criterion will be included since it is a necessary point in explaining the results gleaned from this procedure. Before proceeding, several definitions are necessary:

Y' = Y estimate from regression equations

$\underline{\hat{B}}$ = column vectors of Bs (regression coefficients)

$\underline{g}$ = uncorrected sums of cross products of Y with

TABLE 1: OBSERVATIONAL DATA

Observation Number	H_b	a	M	V_{ON}^{***}	V_{LONG}^{***}	D_C	C_L^{***}	D_{50}	H_T	V_S	T	Y
1-A	2.3	11R	3.3	4.8	2.7	800	1.3	0.25	0.5	7.1	7.3	3.6
2-A	1.6	16R	3.5	15.3	-2.7	800	-1.2	0.14	-0.4	5.9	6.3	5.0
3-A	1.5	25R	3.9	16.7	-2.9	800	1.6	0.17	-1.0	3.7	7.1	3.3
4-A	4.2	7L	5.2	0.0	0.0	800	1.8	0.30	4.0	6.4	6.9	16.7
5-A	2.2	16R	4.5	9.3	5.2	800	0.0	0.09	1.1	3.1	4.0	10.0
6-A	1.5	14R	2.8	7.2	5.4	800	0.4	0.22	1.8	2.1	6.7	3.9
7-A	2.1	12R	3.5	6.3	5.7	800	0.1	0.30	2.2	2.2	6.7	3.3
2-B	3.0	10R	4.9	14.3	0.0	1600	1.1	0.26	2.9	7.2	6.3	5.0
3-B	3.8	15L	6.5	9.0	-0.8	1600	1.0	0.18	1.8	4.6	6.9	8.3
4-B	5.7	10R	4.3	12.7	-0.7	1600	1.0	0.36	2.4	2.5	6.4	6.3
5-B	4.1	12R	4.0	21.3	-5.7	1600	0.8	0.16	1.1	2.7	5.8	8.4
1-C	5.0	8R	2.3	10.4	-8.1	2400	1.1	0.28	1.8	10.5	7.3	5.6
2-C	2.5	5R	4.0	15.9	-4.3	2400	-0.7	0.36	0.7	7.6	7.1	6.7
3-C	5.2	15L	3.5	12.8	2.3	2400	0.6	0.23	1.1	3.4	6.9	5.6
4-C	3.2	6R	3.8	-12.7	-6.5	2400	-0.6	0.14	1.0	3.0	6.5	4.0
5-C	4.5	5R	8.3	15.4	-7.2	2400	-0.7	0.20	1.8	4.2	6.4	2.6
1-D	4.3	2R	5.2	13.9	5.6	3200	-1.4	0.24	0.6	8.7	7.7	3.9
2-D	4.5	1R	6.3	9.7	2.6	3200	0.8	0.25	1.3	4.5	6.3	4.2
3-D	1.5	0	1.7	0.0	-6.7	3200	-0.1	0.16	-1.2	5.6	6.2	0.8
5-D	4.1	1L	8.8	2.0	-0.1	3200	0.7	0.28	0.0	1.0	6.4	4.0
1-E	5.0	2R	4.3	7.5	-8.0	4000	0.4	0.37	3.8	6.4	7.3	2.5
3-E	4.1	2R	3.0	20.0	0.0	4000	-1.1	0.20	0.3	15.0	5.3	1.9
4-E	6.7	2L	5.9	0.0	13.0	4000	0.2	0.35	5.2	4.6	7.2	3.3
5-E	3.7	4R	3.5	21.3	0.0	4000	1.3	0.22	1.1	5.5	5.4	2.5
1-F	4.0	0	3.5	6.0	-1.8	4800	-1.5	0.17	3.2	6.8	7.7	5.0
2-F	4.9	5L	5.6	18.2	-1.6	4800	-0.3	0.29	1.0	3.3	5.7	4.2
3-F	4.7	4R	4.5	5.9	-14.5	4800	-0.1	0.13	-0.2	6.9	5.8	8.3
4-F	5.5	2R	5.6	6.5	-14.0	4800	-1.2	0.27	4.0	6.7	6.4	5.0
2-G	2.7	4R	5.0	-10.9	-13.9	5600	-1.1	0.15	1.9	2.3	7.2	3.3
4-G	4.6	2R	6.5	18.3	0.0	5600	0.3	0.15	1.4	1.9	6.4	2.5
6-G	4.2	3L	5.0	22.0	-3.9	5600	-0.1	0.13	2.5	6.1	5.4	3.1

TABLE 1 (continued)

Observation Number	H_b	a	M	V_{ON}^{***}	V_{LONG}^{***}	D_C	C_L^{***}	D_{50}	H_T	V_S	T	Y
6-G	3.9	4L	5.0	13.3	-7.7	5600	-1.1	0.19	2.1	10.4	6.4	3.3
1-H	5.0	7R	4.9	7.1	-21.9	6400	-1.1	0.13	2.7	7.3	7.3	0.4
2-H	5.2	3R	2.2	16.9	-6.2	6400	-0.2	0.17	-0.1	15.5	5.8	2.5
4-H	6.3	3L	4.8	9.0	2.2	6400	0.9	0.25	3.2	2.8	6.4	3.3
5-H	6.2	0	7.2	0.9	-7.2	6400	-0.5	0.16	4.9	10.1	6.4	7.5
4-D**	5.2	7L	7.0	8.2	1.4	3200	1.6	0.18	4.3	7.1	7.2	11.1
2-E**	2.8	2L	5.0	8.5	-0.7	4000	1.4	0.16	0.4	2.2	6.5	6.7
5-F**	3.5	1R	3.0	8.6	-3.6	4800	0.2	0.10	1.3	8.7	6.4	6.7

REFERENCE LEVELS USED TO MAKE ALL COMPUTER INPUTS POSITIVE

	0.0	45R	0.0	-100.0	100.0	0.0	10.0	0.0	5.0	0.0	0.0	0.0

** Used for verification only.

*** Minus numbers indicate away from the canyon for V_{LONG} and C_L, and offshore for V_{ON}.

successive X's

SS_Y = sum of squares of Y

The first step of the procedure is to compute SS_Y by the equation:

$$SS_Y = \sum(Y-\overline{Y})^2 \tag{2}$$

by using the computing formula:

$$SS_Y = \sum Y^2 - \overline{Y}\sum Y \tag{3}$$

Since the mean value of the observed Y values, $\overline{Y}$, is the same as the mean $\overline{Y}'$ of the computed Y' values, then $SS_{Y'}$ can be computed using:

$$SS_{Y'} = \sum Y'^2 - \overline{Y}\sum Y \tag{4}$$

where

$$\sum Y'^2 = \underline{\hat{B}}^T \underline{g} \tag{5}$$

If $\sum Y'^2 = \sum Y^2$, this would indicate that the variability of Y and Y' were the same from (3) and (4).

The criterion for ranking the parameters in their order of importance is based on the degree to which any single parameter or combination of parameters "accounts for" the variability of Y. In other words, if Y' for each set of parameters was exactly equal to each Y observed, then 100% of the variability of Y would be "accounted for". The percentage of the variability each parameter or combination of parameters "accounts for" Y is computed from:

$$\text{Percent Red.} = 100(SS_{Y'})/(SS_Y) \tag{6}$$

This quantity is informally called the "percentage SS reduction

of Y" and the machine output lists this quantity for all stages of the analysis. The reduction in the SS_Y is a measure of the mathematical association between variables (here the linear association) and it is not necessarily a measure of the physical relationship.

To evaluate the relative importance of any parameter or combination of parameters on this least-square basis, the scanning routine involves the selection of the strongest single parameter, the strongest pair of parameters, and continues until the strongest combinations are examined.

To illustrate the foregoing statement, a fictitious machine output for three parameters is given in Table 2.

TABLE 2: FICTIOUS EXAMPLE OF THREE X'S

X'S	NUMBER OF X'S	PERCENT SS REDUCTION
	ONE AT A TIME	
1		25.0
2		50.0
3		12.5
	TWO AT A TIME	
1,2		70.0
1,3		50.0
2,3		25.0
	THREE AT A TIME	
1,2,3		75.0

The strongest parameter is X_2 with a "percent SS reduction" of 50%, the strongest pair of parameters is X_1 and X_2 with a "percent SS reduction" of 70%. From this, the net conbribution of X_1, in combination with X_2, is 70%-50% = 20%. This difference from the value of X_1 alone, 25%, essentially indicates some

redundancy exists between X_1 and X_2.

In this example X_3 is obviously weakest, and its contribution <u>in the presence of both</u> X_1 <u>and</u> X_2 is 75%-70% = 5%. Comparison with X_3 taken alone also shows that some data redundancy is present.

In this example, the difference between the parameters is sufficiently large so that ranking them as to importance is relatively easy, but in other real problems, the differences may be small so that ranking is at least partially subjective.

If non-linear relations are suspected or known, conventional transformations of the parameters may be made before using the program. Transformations such as log X, X^2, e^{-X}, etc., can be used to help "reduce the SS". A logarithmic transformation of distance from the canyon was used in this study.

Several items should be noted here before proceeding to the results and conclusions, they are:

(1) A small "percentage SS reduction" indicates either erroneous data or omission of important variables;

(2) Several combinations of parameters can be made which will yield different "percent SS reduction" for the same variable; and,

(3) Ranking of the parameters can be different depending on subjectiveness of the investigator.

Items (2) and (3) result from the fact that the strongest combination which fits with the previous combination might not

be the first strongest, but may be the second or third, whereas the first strongest will fit in a different series. All variables eventually make an appearance, although their orders in various series are different, with correspondingly different values. A series is like that described in the fictitious example and Table 2, i.e., a series for this example is X_1; X_1, X_2; X_1, X_2, X_3.

The distinct advantage of this procedure over other step-wise multiple linear regression programs, i.e., the BMD series developed by UCLA [2], is the capability of looking at the many combinations of parameters. Other programs create a new combination, e.g., four at a time from three at a time, by adding a new parameter that gives the "best goodness of fit." As can be seen from the comparison between "Whirlpool" (Table 3) and a typical BMD output (Table 4) the ranking may be different and erroneous for the BMD approach.

TABLE 3: CONTRIBUTIONS BY ADDITIONAL VARIABLES AMONG THE EIGHT STRONGEST INDEPENDENT VARIABLES TAKEN JOINTLY

VARIABLE	% SS ACCOUNTED FOR INDIVIDUALLY	X'S IN COMBINATION	% SS ACCOUNTED FOR BY COMBINATION	CONTRIBUTION OF NEW X	INCREASE OR DECREASE RELATIVE TO ORIGINAL CONTRIBUTION
D_C	15.98	D_C	15.98	15.98	
a**	1.17	D_C,a	25.61	9.63	INCREASE OF 8.46%
H_T	3.52	D_C,a,H_T	32.46	6.85	INCREASE OF 3.33%
T	.67	D_C,a,H_T,T	37.93	5.47	INCREASE OF 4.80%
V_{LONG}	1.61	D_C,a,H_T,T,V_{LONG}	42.65	4.72	INCREASE OF 3.11%
V_{ON}**	.10	D_C,a,H_T,T,V_{LONG},V_{ON}	44.21	1.56	INCREASE OF 1.46%
H_b**	.60	D_C,a,H_T,T,V_{LONG},V_{ON},H_b	46.52	2.31	INCREASE OF 1.71%
D_{50}	2.60	D_C,a,H_T,T,V_{LONG},V_{ON},H_b,D_{50}	48.43	1.91	DECREASE OF .69%

** THIS COMBINATION IS SECOND STRONGEST (TABLE 3).

TABLE 3A: CONTRIBUTIONS BY ADDITIONAL VARIABLES AMONG THE SIX STRONGEST INDEPENDENT VARIABLES TAKEN JOINTLY

VARIABLE	% SS ACCOUNTED FOR INDIVIDUALLY	X'S IN COMBINATION	% SS ACCOUNTED FOR BY COMBINATION	CONTRIBUTION OF NEW X	INCREASE OR DECREASE RELATIVE TO ORIGINAL CONTRIBUTION
D_C	17.86	D_C	17.86	17.86	
H_b	.10	D_C, H_b	33.18	15.32	INCREASE OF 15.22%
a	1.17	D_C, H_b, a	40.91	7.73	INCREASE OF 6.56%
V_{LONG}	1.61	D_C, H_b, a, V_{LONG}	47.09	6.18	INCREASE OF 4.57%
T	1.31	D_C, H_b, a, V_{LONG}, T	51.47	4.38	INCREASE OF 3.07%
V	2.60	D ,H ,a,V ,T,V	54.67	3.20	INCREASE OF .60%

TABLE 4: A TYPICAL BMD TYPE OUTPUT FOR A STEPWISE MULTIPLE LINEAR REGRESSION PROGRAM.

RELATIVE RANKING WITH OTHER COMBINATIONS	X'S	PERCENT SS REDUCTION
1	D_C	15.98
1	D_C, H_b	27.10
2	D_C, H_b, D_{50}	31.33
4	D_C, H_b, D_{50}, a	36.14
3	D_C, H_b, D_{50}, a, H_T	41.25
6	$D_C, H_b, D_{50}, a, H_T, V_{LONG}$	43.36
1	$D_C, H_b, D_{50}, a, H_T, V_{LONG}, T$	46.67
1	$D_C, H_b, D_{50}, a, H_T, V_{LONG}, T, V_{ON}$	48.43

5. RESULTS

The results of the investigation are presented in two parts dealing with the subproblems.

Direction of Sand Movement

Table 1 is a tabulation of the data gathered during the various observation periods. A perusal of this table reveals that all 36 observations used for final analysis indicated positive sand movement toward the canyon. In no case was there movement in the opposite direction.

Rate of Sand Movement

The results for this particular problem were the outputs of the "Whirlpool" program. Table 5 presents the five best "percent SS reduction" for eight combinations of eleven independent parameters. The maximum total "percent SS reduction" for this set of data was 51.54% (linear) and 58.02% (non-linear) for all eleven parameters considered together. As can be seen from Table 3, the maximum "percent SS reduction" for eight linear independent variables was 48.43% which was considered sufficient since this accounted for 93.97% of the original "percent SS reduction". Table 3A shows that the maximum "percent SS reduction" for the non-linear case with six independent variables was 54.67% which accounted for 94.21% of the original "percent SS reduction".

Table 3 lists the contributions by each parameter among

TABLE 5: THE STRONGEST PERCENT REDUCTION IN SAND DRIFT SUM OF SQUARES ATTRIBUTABLE TO EACH OF SEVERAL COMBINATIONS OF ELEVEN INDEPENDENT VARIABLES (TOTAL PERCENT REDUCTION, ALL X'S 51.54)

X'S	NUMBER OF X'S	PERCENT SS REDUCTION
	ONE AT A TIME	
D_C		15.98
C_L		10.51
H_T		3.52
V_{ON}		2.60
M		1.63
	TWO AT A TIME	
D_C, H_b		27.10
D_C, a		25.61
D_C, H_T		25.27
D_C, M		20.47
D_C, V_{ON}		19.57
	THREE AT A TIME	
D_C, H_T, a		32.46
D_C, H_b, D_{50}		31.33
D_C, H_b, a		31.09
D_C, H_b, V_{ON}		31.05
D_C, H_b, T		29.95
	FOUR AT A TIME	
D_C, H_T, a, T		37.93
D_C, H_T, a, D_{50}		37.12
D_C, H_b, V_{ON}, T		36.75
D_C, H_b, a, D_{50}		36.14
D_C, H_b, H_T, D_{50}		35.69
	FIVE AT A TIME	
D_C, H_T, a, T, V_{LONG}		42.65
D_C, H_T, a, T, V_{ON}		41.28
D_C, H_T, a, D_{50}, H_b		41.25
D_C, a, T, H_b, V_{ON}		40.76
D_C, a, T, H_T, D_{50}		40.21
	SIX AT A TIME	
$D_C, a, T, H_T, H_b, V_{LONG}$		44.32
$D_C, a, T, H_T, V_{ON}, V_{LONG}$		44.21
$D_C, a, T, H_T, D_{50}, V_{LONG}$		43.60
$D_C, a, T, H_T, C_L, V_{LONG}$		43.53
$D_C, a, T, H_T, H_b, V_{ON}$		43.38

TABLE 5 (continued)

X'S	NUMBER OF X'S	PERCENT SS REDUCTION
	SEVEN AT A TIME	
$D_C, a, T, H_T, H_b, D_{50}, V_{LONG}$		46.67
$D_C, a, T, H_T, H_b, V_{ON}, V_{LONG}$		46.52
$D_C, a, T, H_T, H_b, V_{ON}, D_{50}$		46.35
$D_C, a, T, H_T, C_L, D_{50}, V_{LONG}$		44.97
$D_C, a, T, H_T, C_L, V_S, V_{ON}$		44.94
	EIGHT AT A TIME	
$D_C, a, T, H_T, H_b, D_{50}, V_{ON}, V_{LONG}$		48.43
$D_C, a, T, H_T, H_b, D_{50}, V_{ON}, V_S$		48.34
$D_C, a, T, H_T, H_b, V_{ON}, V_{LONG}, V_S$		47.70
$D_C, a, T, H_T, C_L, V_{ON}, V_{LONG}, V_S$		47.43
$D_C, a, T, H_T, H_b, D_{50}, V_{LONG}, V_S$		47.33

the eight strongest independent variables taken jointly. It should be noted that levels two, six, and seven, are the second strongest combinations, since the first strongest did not mesh into the scheme. It is evident that distance from the canyon was the strongest contributor with a "percent SS reduction" of 15.98%. Even though longshore current and mean slope appeared in the five strongest individual contributors, they did not appear in the final analysis. Table 3A lists the contributions by each parameter among the six strongest independent variables taken jointly. As contrasted to the linear case, all levels were the strongest combinations. The strongest contributor was again distance from the canyon with a "percent SS reduction" of 17.86%.

Table 6 shows the range and mean value of sand drift at each station over the period of investigation. The trend of the mean rates was inversely proportional to the distance from the canyon. The regression equation that resulted from the linear analysis:

$$Y = 14.403+0.496H_b+0.109a+0.147M-0.069V_{on}-0.069V_{long}$$
$$-0.001D_c+0.514C_l-8.364D_{50}+0.524H_t+0.172V_s-0.921T \quad (7)$$

yielded the following answers when the data from 4D, 2E, and 5F (corrected to reference levels, Table 2) were inserted:

Sample Number	Observed Drift	Computed Drift	Residuals	Percent Accuracy
4D	11.1	9.9	1.2	89.2
2E	6.7	5.1	1.6	76.1
5F	6.7	5.7	1.0	85.1

The average accuracy of these tests on the regression coefficients was 83.5%. It was previously noted that these three observations were excluded from the data processing due to insufficient grain count.

TABLE 6: RANGE AND MEAN RATE
OF SAND DRIFT AT EACH STATION

STATION	DISTANCE FROM CANYON	RANGE OF SAND DRIFT	MEAN RATE
A	800	3.3-16.7FT/MIN	6.4FT/MIN
B	1600	5.0-8.4 FT/MIN	7.0FT/MIN
C	2400	2.6-6.7 FT/MIN	4.9FT/MIN
D	3200	0.8-4.2 FT/MIN	3.2FT/MIN
E	4000	1.9-7.1 FT/MIN	3.5FT/MIN
F	4800	5.0-10.0FT/MIN	7.4FT/MIN
G	5600	2.5-3.3 FT/MIN	3.1FT/MIN
H	6400	0.0-7.5 FT/MIN	3.3FT/MIN

6. CONCLUSIONS

The sampling technique was designed to provide distinction between dispersion and drift in either direction. Sands injected toward the canyon (orange) were never found, while those injected away (green) were found in all observations. These results indicate that dispersion and drift away from the canyon did not occur during this study period. It can be concluded then, that during the winter/early-spring season, within the area investigated, the swash-zone sand movement is directed toward the canyon.

The parameters chosen have a definite, though not completely understood, effect on sand drift. The assumptions made were carefully considered and are believed to be correct as far as beach sand and ocean interactions are known. Without more concrete knowledge of the interactions, the only conclusions which can be drawn are statistical in nature. Consequently, it is felt that a "Whirlpool" type program is a superb method for ranking the important parameters.

Since in the linear and non-linear cases there was a maximum of 58.02% "percent SS reduction", this is an excellent indication that imprecise techniques in the measurements led to data "noise". The methods described in Appendix I involved many approximations. Exact measurements of these parameters, however, would have required more elaborate instruments than were available.

Another source of data "noise" could have resulted from a poor choice of criteria in determining rate of drift. Even though the "25%/steep slope" criterion gave the best results of those evaluated, there may have been a more optimum selection.

Of the parameters investigated, there are two that may not be indicative of the energy relationships which they were chosen to represent. There are two observable components of swash-velocity, onshore and longshore. Only the onshore one was used in this study. A more desirable parameter may have been the longshore component, but this value was not used because no observation of the nearshore angle of approach was made. The value used for mean grain size was a function of the drift rate time. Since the latter was based on arbitrary criteria, the mean grain size would similarily contribute to data "noise". Therefore, the longshore component of swash-velocity might replace onshore swash-velocity and mean grain size as being more representative of the energy distribution on and along the swash-zone.

The final parameter suspected of generating data "noise" was longshore currents. These values were the results of short-term observations (two minutes or less). More representative values might have been obtained by measuring long-term mean currents.

Another factor contributing to this relatively small "percent reduction" was the limited interval of time over which the study

was conducted. The study did not have a sufficient time span for the variability of the parameters to reach their maximum possible range of values.

The large value of "percent SS reduction" for distance from the canyon may be partially attributed to the fact that there were only eight variations of the distance available, causing a possible biasing effect. More random values of the distance input may have yielded less promising results.

Ignoring the limitations of short-term observations of longshore current, the low individual "net percent SS reduction" obtained for this parameter can be interpreted to mean that longshore current does not significantly contribute to the swash-zone sand movement.

In view of the preceding facts, no concrete conclusions can be drawn concerning the relative importance of the observed parameters in affecting the rate of drift. In light of earlier energy considerations, it is not unreasonable, however, to assume that the relative ranking of the parameters in the non-linear case is indeed indicative of the real situation. Possible exceptions to this ranking include the apparently negligible contribution by mean slope and longshore current.

This study was not completely restricted to evaluating only the statistical results. Five individual phi range rates were determined but not used in the statistical analysis. Inspection of these rates revealed that with increasing grain

size, the rates decreased proportionately to the point where no movement existed in the largest phi range (Table 7). This fact implies that larger grains either exhibit no longshore movement or that the rates were too small to be detected during the observational period.

Another interesting aspect of this study was the highly satisfactory performance of the sampling device. It is an improvement over other sampling techniques in that a single observation will provide conclusive evidence of direction of sand movement or dispersion.

Finally, angle of approach, wind alongshore, and longshore current should, by classical concepts, govern the direction and somewhat influence the rate of sand movement, providing the study area has a straight beach with relatively parallel offshore contours [10]. It is obvious from the data in Table 1 that in many of the observed cases these relationships did not hold for the swash-zone. Therefore, it can be concluded that either the swash-zone movement is affected differently than the net littoral movement, or that the canyon has an overriding effect on the movement of sand in the swash-zone.

TABLE 7: SAND DRIFT RATES FOR EACH OBSERVATION FOR PHI RANGES -1 THROUGH 4

OBSERVATION NUMBER	PHI RANGES -1 TO 0	0 TO 1	1 TO 2	2 TO 3	3 TO 4
1-A	1.4	2.5	3.6	3.8	3.1
2-A	0.0	2.0	2.0	5.6	3.3
3-A	0.0	3.2	3.8	3.3	3.3
4-A	2.5	2.9	6.7	3.3	5.0
5-A	0.0	0.0	4.5	5.0	16.7
6-A	0.0	2.0	3.8	2.0	3.6
7-A	0.0	2.3	2.4	2.5	2.5
2-B	1.8	4.2	5.0	4.5	4.2
3-B	0.0	1.9	2.0	7.1	2.0
4-B	2.5	2.8	6.3	5.6	5.6
5-B	0.0	3.3	3.3	16.7	25.0
1-C	2.5	1.7	3.8	4.5	8.3
2-C	0.0	6.3	6.7	6.3	6.7
3-C	0.0	5.0	5.0	5.6	6.3
4-C	0.0	0.0	3.3	3.6	8.3
5-C	0.0	2.3	2.5	2.5	12.5
1-D	0.0	1.4	2.5	4.2	5.0
2-D	0.0	2.8	3.8	4.5	12.5
3-D	0.0	0.0	5.0	7.1	10.0
5-D	1.7	2.0	3.6	3.3	16.7
1-E	0.0	2.6	3.3	8.3	12.5
3-E	0.0	1.8	1.9	1.8	2.0
4-E	0.0	3.1	3.3	8.3	12.5
5-E	0.0	1.8	2.5	3.3	12.5
1-F	0.0	0.0	3.8	5.0	10.0
2-F	0.0	1.6	4.0	4.2	3.8
3-F	0.0	0.0	7.1	7.1	7.1
4-F	0.0	2.3	5.0	10.0	25.0
2-G	0.0	0.0	3.3	3.3	16.7
4-G	0.0	4.0	3.3	2.5	6.3
5-G	0.0	1.2	3.3	2.9	3.1
6-G	0.0	0.0	5.0	3.1	3.3
1-H	0.0	2.3	2.0	2.0	2.5
2-H	0.0	2.0	2.0	10.0	16.7
4-H	0.0	3.1	3.3	12.5	16.7
5-H	0.0	0.0	5.0	25.0	50.0

7. FUTURE STUDY

Based on the assumptions made in this thesis, extending the study to include sampling: at greater distances on both sides of the canyon; in the canyon; in the surf zone; and through a vertical profile, would be highly informative. Additionally, the study period should be lengthened, and more precise techniques should be used to measure the desired parameters.

8. ACKNOWLEDGMENTS

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APPENDIX I

DESCRIPTION AND MEASUREMENT OF THE STUDIED VARIABLES

H_b

Height of the Breaking Waves

A man was placed at the mean water level with a stadia rod while another sighted across the mean breaker level, recording the height on the stadia rod. The average of these measurements taken during the observation period was used for the value of breaker height.

a

Angle of Approach

A Brunton Compass was utilized in measuring the angle of approach. One man pointed the compass normal to the approaching wave crests while another man lined up the beach face. At least two measurements were taken during each observational period. The final value was taken to be the average of these measurements.

M

Mean Slope of the Swash-zone

A Brunton Compass was used to measure the beach slope in the mid swash-zone.

V_{ON} and V_{LONG}

Onshore and Longshore Wind

A standard Navy wind measuring set, AN/PMQ-3C, was used to measure wind speed and direction. Three values were taken per observational period. These values were averaged and broken down into onshore and longshore components.

D_C

Distance from the Canyon

Distances from the canyon were surveyed with a transit and stadia rod using the Moss Landing Pier as a base point.

C_L

Longshore Current

Three to five drift bottle measurements were made over a 100 foot run during each observational period. These values were averaged and the result designated as longshore current.

D_{50}

Mean Grain Size

Mean grain size was determined from a cumulative percent curve of the fluorescent tracer grains captured up to and including the time designated as the Drift Rate Time.

H_T

Height of the Tide

Height of the tide was calculated from standard tide tables for the time halfway through each observational period.

T

Period of the Waves

Wave period was measured at the start of, halfway through, and at the end of each sampling day. The periods of 30 waves passing the end of the Moss Landing Pier were averaged for each wave measurement. The resulting values were applied to the nearest observational period.

V_S

Swash-Velocity

Swash-velocity was determined from two measured values, swash-length and swash-period. The swash-length was the average length of 15 or more swashes. The swash-period was the average of a series of full swashes. A full swash was considered to be one that was not noticeably interfered with

by backwash and uprush. The average swash-length was doubled and then divided by the average swash-period to give a value for average swash-velocity for the observational period.

Y

Rate of Sand Drift

Rate of sand drift is discussed in the Data Analysis section.

APPENDIX II

Sample Data Analysis Sheets

SAMPLE

DATA OBSERVATION SHEET

Station __D__ Observation Number __2__ Date __27 Feb.__ Time __1130__

Breaker Height (H_b)			4.5 (ft)
Angle of Approach (a)			1R (°)
Mean Slope of Swash-Zone (M)			6.3 (°)
Wind Speed	10.0 (kts)		
		Wind Onshore(V_{ON})	9.7 (kts)
		Wind Longshore(V_{LONG})	2.6 (kts)
Wind Direction	345 (°) Relative to onshore normal to beach		
Distance from Canyon (D_C)			3200 (ft)
Longshore Current (C_L)			0.8 (ft/sec)
Height of Tide (H_T)			1.3 (ft)
Swash Period	8.9 (secs)		
		Swash Velocity (V_S)	4.5 (ft/sec)
Swash Length	20 (ft)		
Wave Period (T)			6.3 (secs)
Drift Rate Time	12.0 (min)		
Mean Grain Size (D_{50})			0.25 (mm)
Drift Rate (Y)			4.2 (ft/min)
Drift Direction			Toward

Remarks: An identical sheet was prepared for each observation made. Direct measurements were recorded in small notebooks and a mean value obtained prior to tabulation. Subjective determination of mean grain size, rate, and direction of drift concluded the data compilation of each observation.

SAMPLE GRAIN COUNT SHEET

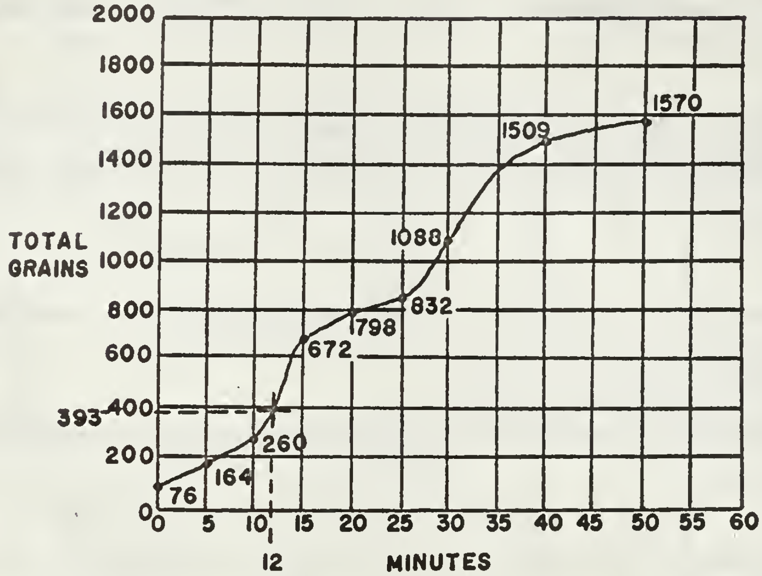
Sample Number 2-D-3 Time After Seeding 15

Median Size(mm)	Phi Range	No. of Splits	No. of Grains	Cumulative Grains	Percent Total	Cumulative Percent
1.5	-1-0	0	0	0	0	0
.75	0-1	0	0	0	0	0
.375	1-2	8	256	328	48.8	48.8
.188	2-3	7	128	224	33.4	82.2
.094	3-4	5	32	120	17.8	100.0
		Total	416	676		

Remarks: A similar sheet was prepared for each sample, and were combined to plot a cumulative grain count curve for each observation. The percent values were only computed for the sample following the drift rate time and were later used in the determination of mean grain size.

SAMPLE CUMULATIVE GRAIN COUNT CURVE

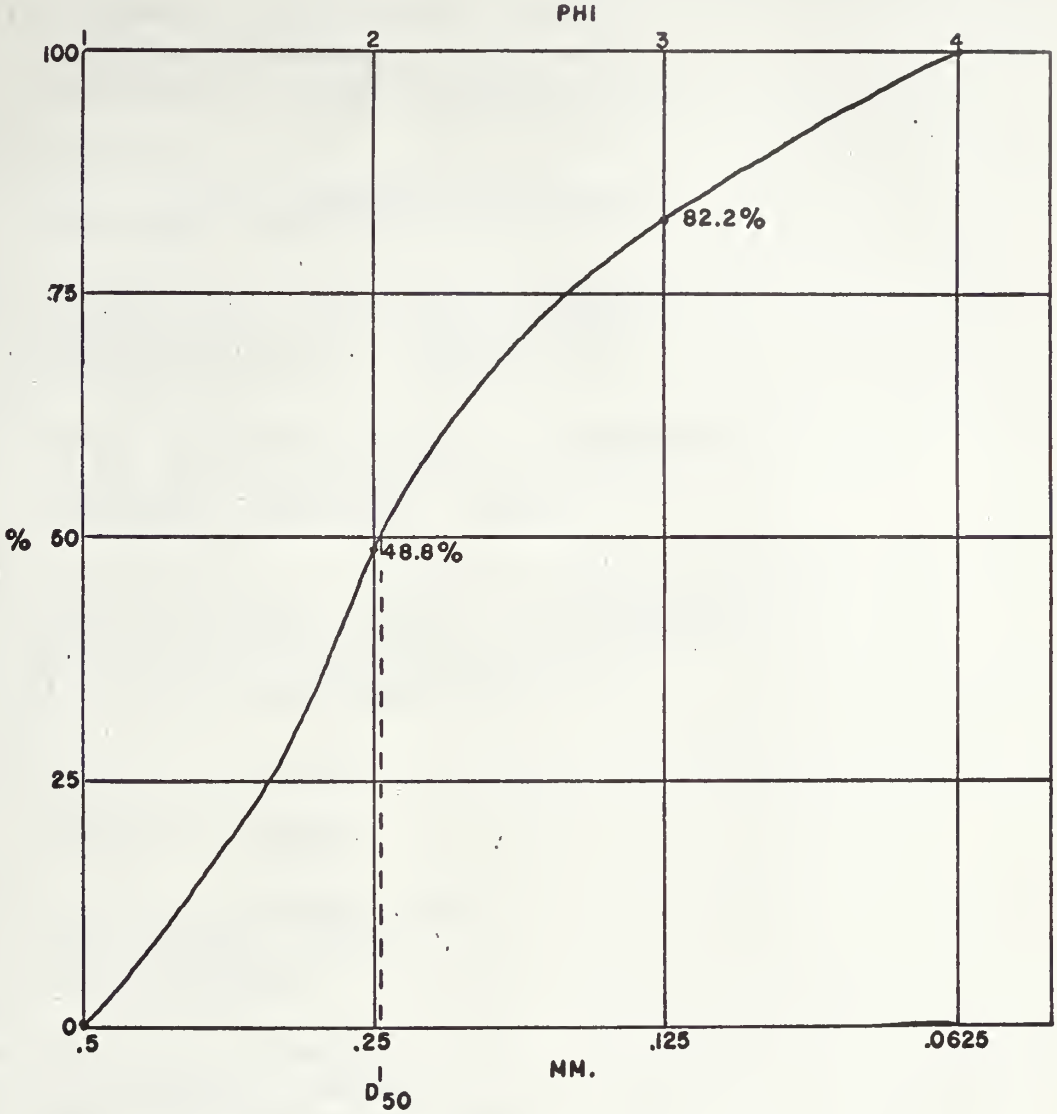
Sample Number 2-D-



Remarks: Similar curves were prepared for each Phi range investigated. Grain counts for each sample were plotted vs. time, and the rate of drift was determined at the time when 25% of the total grains lay on the maximum slope of the curve.

SAMPLE MEAN GRAIN SIZE CURVE

Sample Number 2-D



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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Thesis

5. AUTHOR(S) *(Last name, first name, initial)*

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13. ABSTRACT

The movement of sand in the swash-zone south of the head of Monterey Canyon was studied during February and March, 1966. A stationary sampler was designed and used in conjunction with dyed fluorescent sands to trace the rate and direction of natural sand movement. A sequential multiple linear regression program was used to statistically analyze the effects of this canyon and several other environmental parameters on the movement of beach sand. In all observations made, the sand was found to move toward the canyon head. The canyon also appears to be a major factor affecting the rate of beach sand drift.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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